Impact of left ventricular torsion on flow dynamics: a CFD modeling study using the overset mesh method.

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Background

Intra-cardiac flow is an important component of ventricular function, where vortex formation has been shown to interplay with the function of valves, motion kinetics, wash-out of ventricular chambers and ventricular energetics. The motion kinetics of the ventricle encompass a component perpendicular to the endocardium (~ LV volume change) and a tangential component, also referred to as twisting or torsion. While the former is commonly included in Computational Fluid Dynamics (CFD) models of the LV with moving boundaries, ventricular torsion is commonly discarded. The aim of this study is to investigate the impact of the twisting motion on the left ventricular (LV) intra-cardiac fluid-dynamics by means of a patient-specific CFD model with moving boundaries.

Materials and methods

We recently developed a semi-automatic algorithm to create 4D high-quality structured Boundary Layer (BL) meshes of the LV endocardium with 1-to-1 vertex correspondence starting from clinical images [1]. This algorithm was used to generate 11 highly structured BL meshes derived from CT images in a 81-year-old male patient. Intermediate meshes were generated by means of a cubic Bezier spline interpolation to yield a temporal resolution of 5 ms. The CFD solver Fluent 18.2 used Newtonian blood assumption ($\nu = 2.9 \cdot 10^{-6}\ m^2/s$) to resolve the flow inside the deforming LV by means of an overset grid approach, which decomposes the geometry into a system of overlapping grids: 4D BL meshes (10K elements) as overset and a 3D Cartesian grid (1.7M elements) as background mesh. To assess the impact of torsion on the computed flow field, we superimposed torsional motion as a rotation of the LV sac with respect to the long axis of the chamber [2]. We compared the computational results obtained from simulations (i) without torsion, (ii) with physiological torsional motion and (iii) with torsion augmented by a factor 5 to enhance the differences. Vorticity and wall shear stress (WSS) magnitude were compared at mid- and end-systole (Fig1), by evaluating peak values against the no-torsion case as difference percentage.

Results

Compared to simulations without torsion, the physiological torsional movement increases the vorticity magnitude by 2% during mid-systole, while the WSS magnitude increases by 4%. Changes are also visible in the extension areas for vorticity (end-systole) and WSS (mid-systole). The augmented torsion did not induce significant differences from the physiological case.

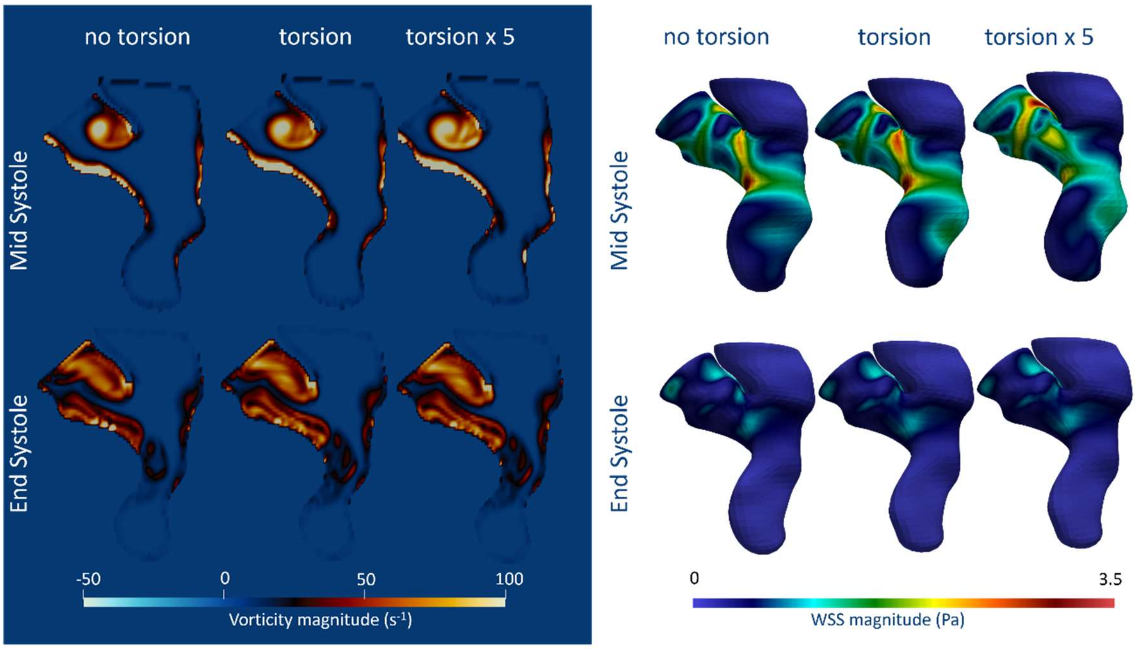

Fig1. Simulated magnitude of vorticity (left) and WSS (right) in the left ventricle (LV) with no torsion, physiological torsion and torsion augmented by a factor 5, at mid systole (first row) and end systole (second row), when the torsional angle is maximum.

Discussion

Torsion enhances vortex formation and extends the regions with higher WSS, but the effect is albeit very limited. As next step, the mitral valve leaflets motion will be included as result of Fluid-Structure Interaction simulations, by taking advantage of the flexible implementation of overset technique.

Acknowledgments

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References

[1] Canè et al, BioMed Research International: Cardiology; 2018 (in press).

[2] Sengupta et al, In JACC: Cardiovascular Imaging, 2008;1(3):366-376 2008.